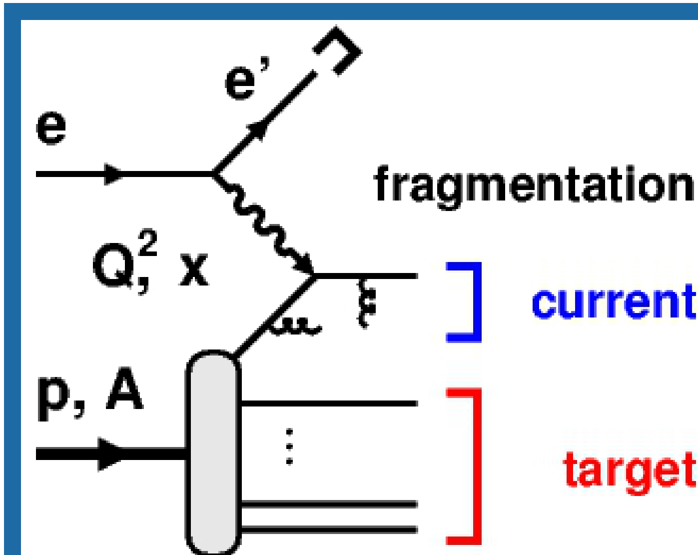
Notes from Target Fragmentation Workshop

Mark D. Baker

05-Nov-2020



CFNS Adhoc Workshop: Target Fragmentation Physics with EIC

28-30 September 2020

Summary

- Wan's talk was well received.
  - Questions hard for her to hear and VERY technical.
  - No clear idea on what to make of the E665 data being peaked at y=+0.6.
- GiBUU+SMM
  - Claim to match HERMES data in current jet.
  - Experience with E665 neutron data similar to ours.
  - Haven't looked at E665 SC data.
- FLUKA (PEANUT)
  - Offered to provide an interface for e+N (i.e. Pythia) to access their e+A (including INC etc.).

GiBUU-Physics of e-A Interactions

Ulrich Mosel

for the GiBUU collab, based on a talk by

Kai Gallmeister

Institut für Theoretische Physik

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Results: EMC & Hermes

$$\frac{\sigma^*}{\sigma_H} = \frac{r_{\rm lead}}{Q^2} + \left(1 - \frac{r_{\rm lead}}{Q^2}\right)\left(\frac{t - t_{\rm P}}{t_{\rm F} - t_{\rm P}}\right)$$

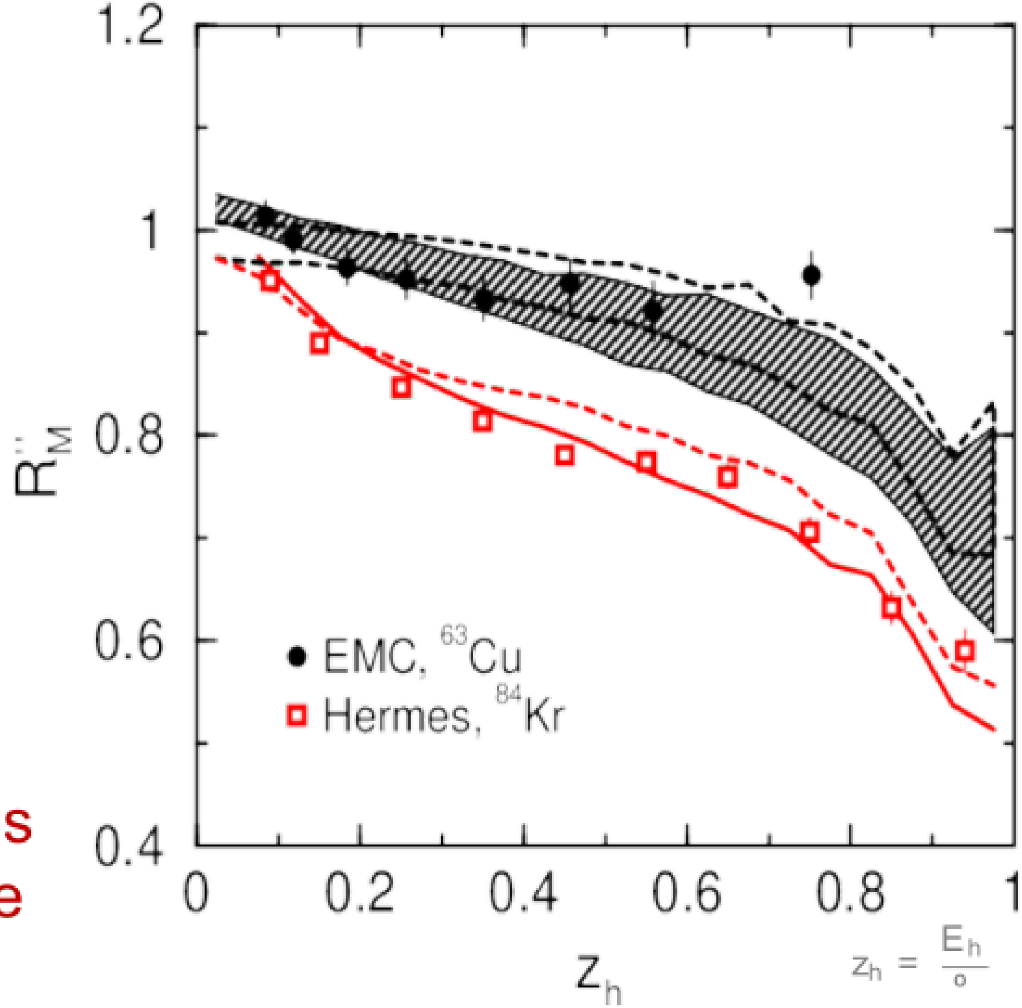
Farrar, Strikman

EMC@100...280 GeV
and
Hermes@27 GeV described
simultanously

!

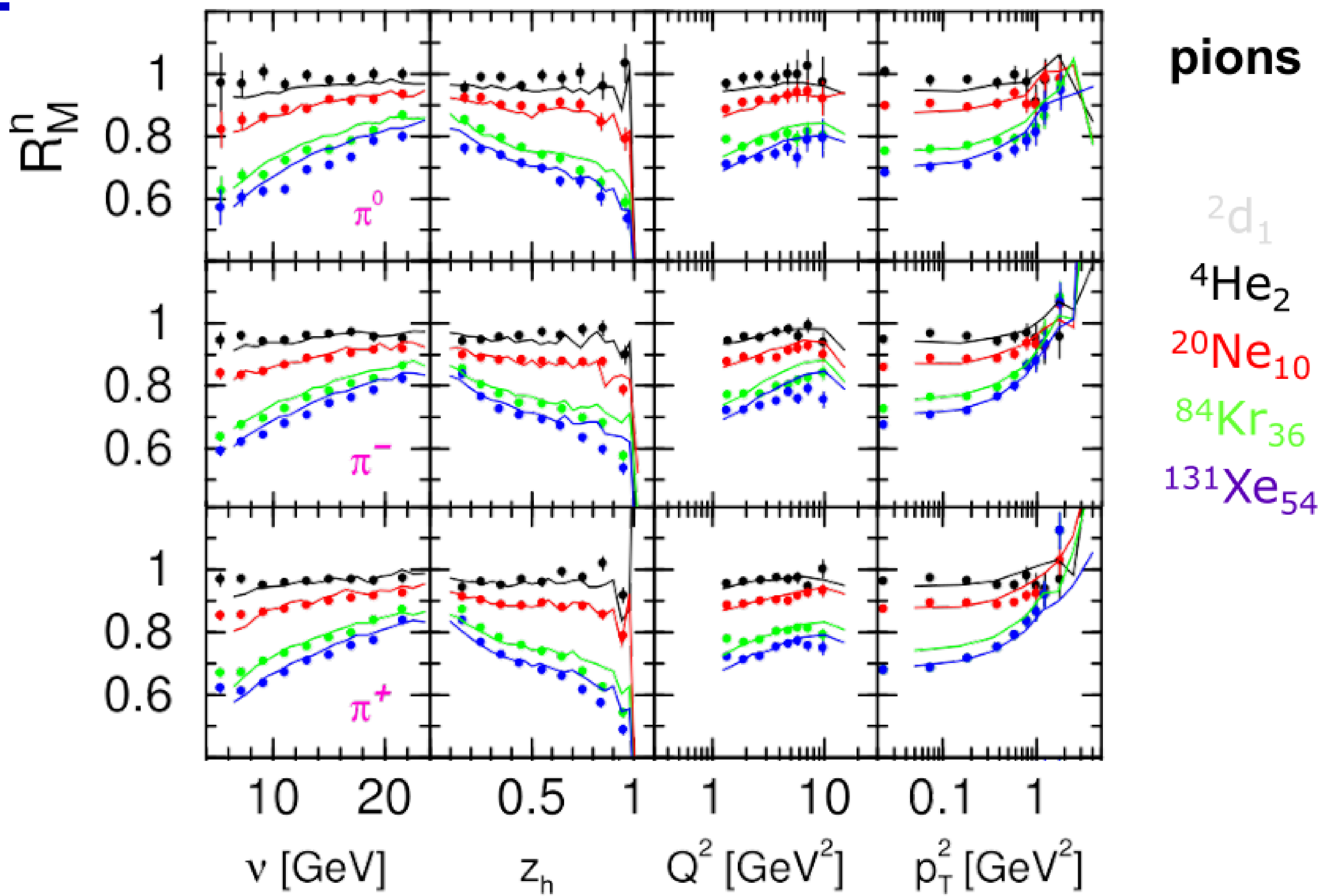
$1/Q^2$ pedestal value?
…small effect!

Prehadronic cross sections increase linearly with time



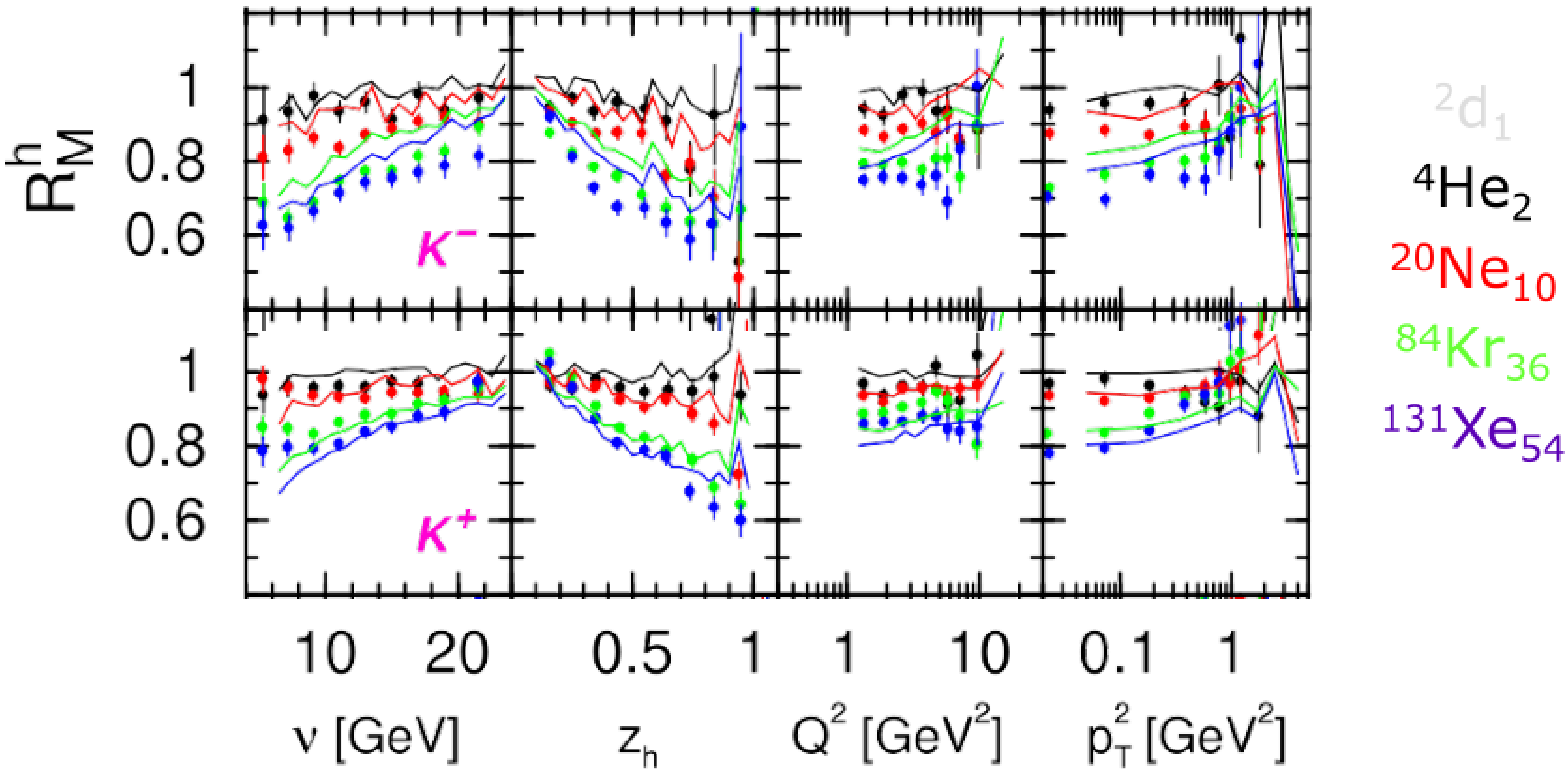
K. Gallmeister, U Mosel: Nucl. Phys. **A801** (2008) 68

Hermes@27: A.Airapetian et al., NPB780(2007)1



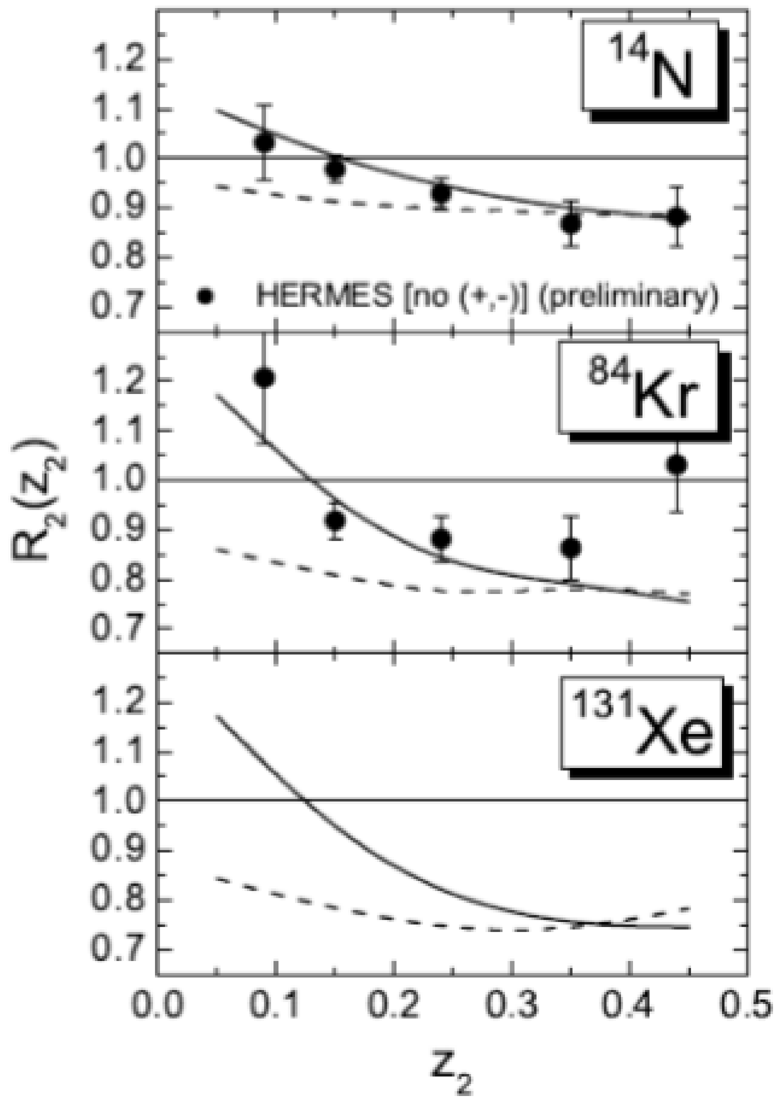
Hermes@27: A.Airapetian et al., NPB780(2007)1

kaons



Attenuation of subleading hadron

Double hadron attenuation:
$z_1 > 0.5$, $z_2 < z_1$



Dashed:
Purely absorptive FSI

Data show „avalanche effect“

Conclusions

- GiBUU handles a wide range of nuclear reactions, from A + A to e + A and ν + A, tested on all these reaction types → FSI are constrained
- GiBUU delivers the complete final state of reactions, i.e. four-momenta of all final hadrons and their positions. It gives single particle phase-space-distributions
- For fragments GiBUU needs afterburner,
  - either by coalescence models: particles close to each other in phase-space are lumped together
  - or by statistical models (following talk by A.L.)
- Prehadronic final state interactions affect both jet-like particles AND fragment excitation: consistent theory must describe both

Nuclear cascade in low-energy nuclear breakup

Alexei Larionov

Institut für Theoretische Physik, Universität Gießen, D-35392 Gießen, Germany

In collaboration with

Mark Strikman

Pennsylvania State University, University Park, PA 16802, USA

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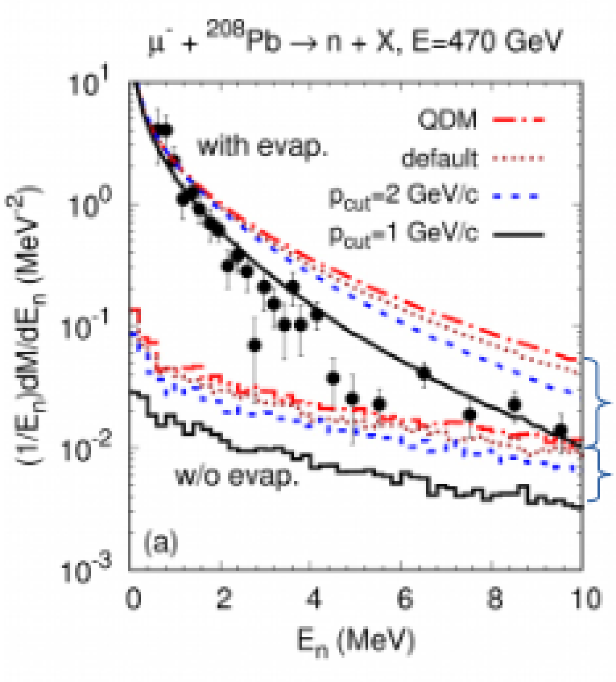
The neutron spectrum contains both the preequlibrium part (cascade particles) and the equilibrium part from the decay of the excited residual nucleus.



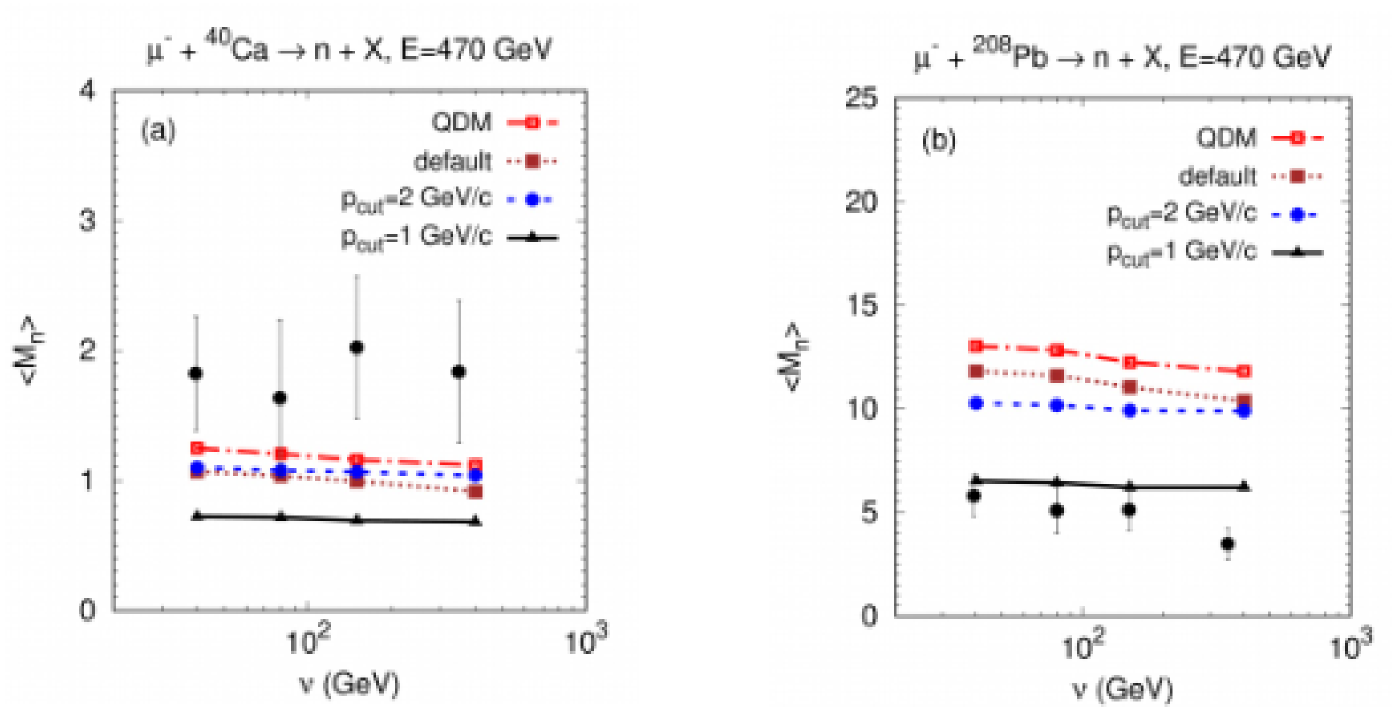
E665 data from
M.R. Adams et al., PRL 74, 5198 (1995)

Cuts:
$\nu > 20$ GeV,
$Q^2 > 0.8$ GeV^2.

- almost all neutrons below 1 MeV are statistically evaporated;
- sensitivity to the model of hadron formation for $E_n > 5$ MeV;
- E665 data for lead target can be only described with very strong restriction on the FSI of hadrons (p_{cut}=1 GeV/c) in agreement with earlier calculations M. Strikman, M.G. Tverskoy, M.B. Zhalov, PLB 459, 37 (1999)

AL, M. Strikman, PRC 101, 014617 (2020), arXiv:1812.08231

Average multiplicity of neutrons with energy below 10 MeV
as a function of virtual photon energy



E665 data from
M.R. Adams et al.,
PRL 74, 5198 (1995)

- no way to describe the E665 data for calcium target with any reasonable model parameters: either problem with data or in the mechanism of interaction of DIS products with nuclear residue

AL, M. Strikman, PRC 101, 014617 (2020), arXiv:1812.08231

Conclusions

- Hybrid GiBUU+SMM model is applied to γ^*A collisions.

- The multiplicity of slow ($E < 10$ MeV) neutrons measured in $\mu^- + {}^{208}Pb$ DIS at E_{beam}=470 GeV (E665 experiment at Fermilab) is a factor of 2 smaller than expected from GiBUU+SMM calculations with default treatment of hadron formation and with QDM model of CT. It can be only reproduced if the hadrons with momenta above 1 GeV/c are not allowed to interact with the rest of the nucleus.

-This indicates the presence of a novel dynamics in the production of hadrons in the nuclear fragmentation region.

- Problem with Ca target: neutron multiplicity is underestimated with any assumption on CT.

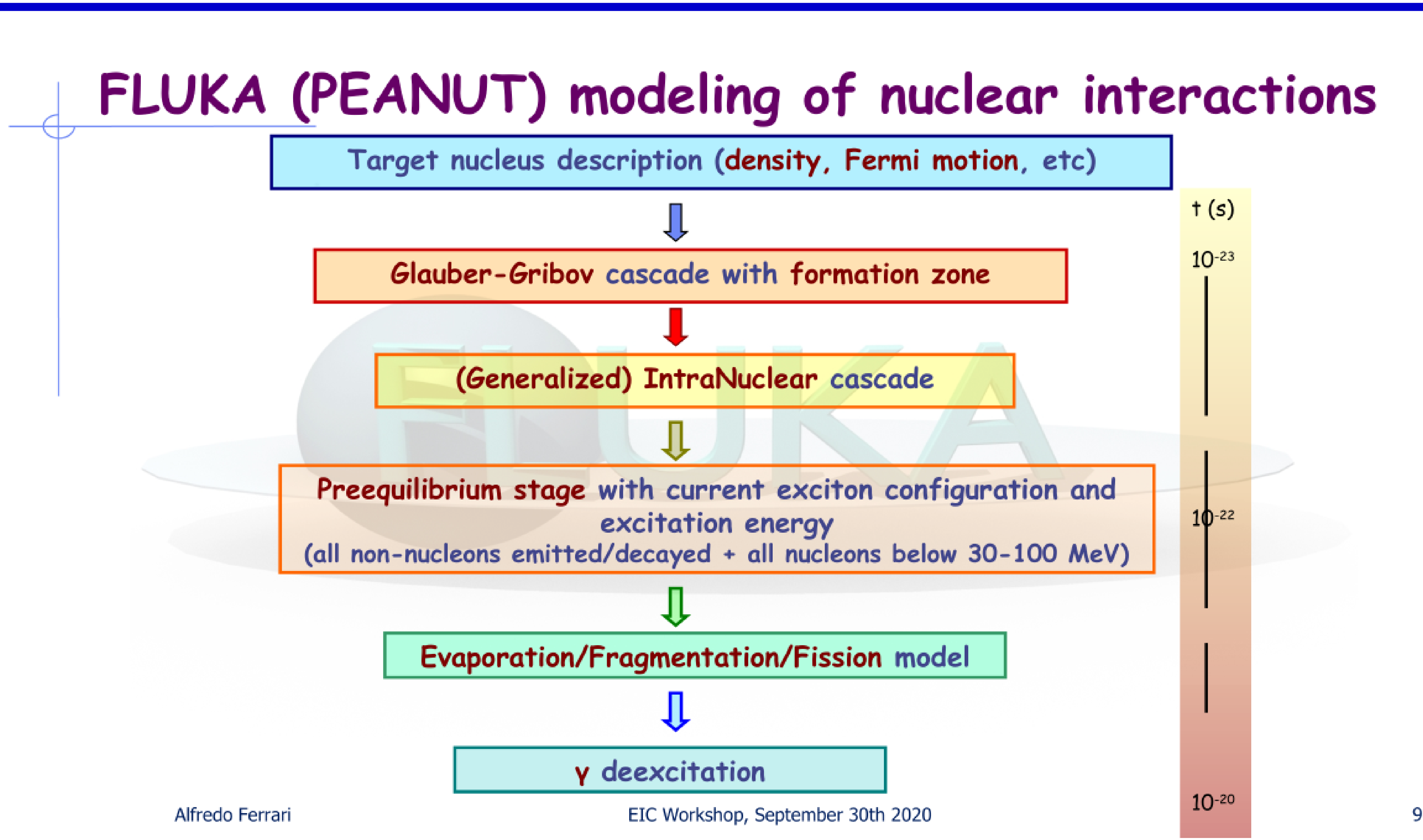
- Different hadron formation scenaria can be tested by slow neutron production (in the target nucleus frame) in UPCs of heavy ions at the LHC and RHIC and, in long run, at the EIC.

The FLUKA (re)interaction models

A (very) short introduction to FLUKA nuclear interaction models

Workshop on Target Fragmentation Physics with EIC
Stony Brook 28-30 September 2020

Alfredo Ferrari,
for the FLUKA Collaboration
Gangneung-Wonju National University, Korea


FLUKA (PEANUT) modeling of nuclear interactions
Target nucleus description (density, Fermi motion, etc)
Glauber-Gribov cascade with formation zone
(Generalized) IntraNuclear cascade
Preequilibrium stage with current exciton configuration and excitation energy
(all non-nucleons emitted/decayed + all nucleons below 30-100 MeV)
Evaporation/Fragmentation/Fission model
γ deexcitation
t (s)
10-23
10-22
10-20
Alfredo Ferrari
EIC Workshop, September 30th 2020
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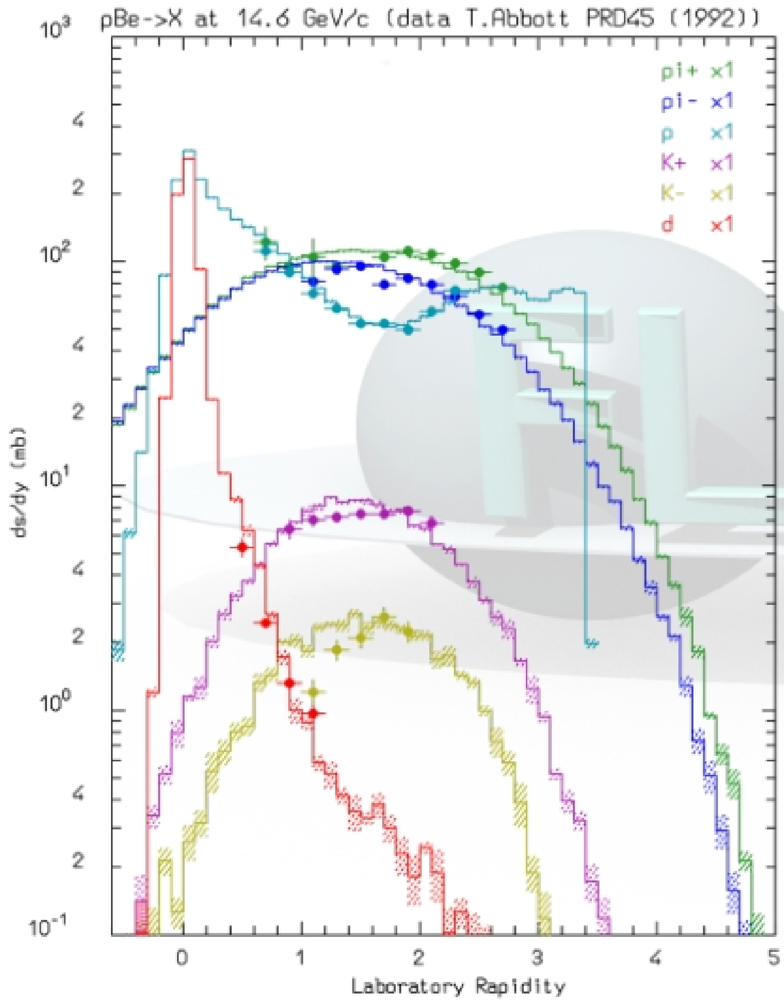
(Generalized) IntraNuclear Cascade in PEANUT

- Primary and secondary particles moving in the nuclear medium
- Target nucleons motion and nuclear well according to the Fermi gas model
- Interaction probability
  σ_{free} + Fermi motion × $\rho(r)$ + exceptions (ex. π)
- Glauber cascade at higher energies
- Classical trajectories (+) nuclear mean potential (resonant for π)
- Curvature from nuclear potential → refraction and reflection throughout the nucleus
- Interactions in projectile-target nucleon CMS → Lorentz boosts
- Multibody absorption for π, μ^-, K^-
- Quantum effects (Pauli, formation zone, coherence length, correlations…)
- Energetic light ion production by coalescence

*Together with the preequilibrium and evaporation steps → **exact conservation** of energy, momenta and all additive quantum numbers, including nuclear recoil*

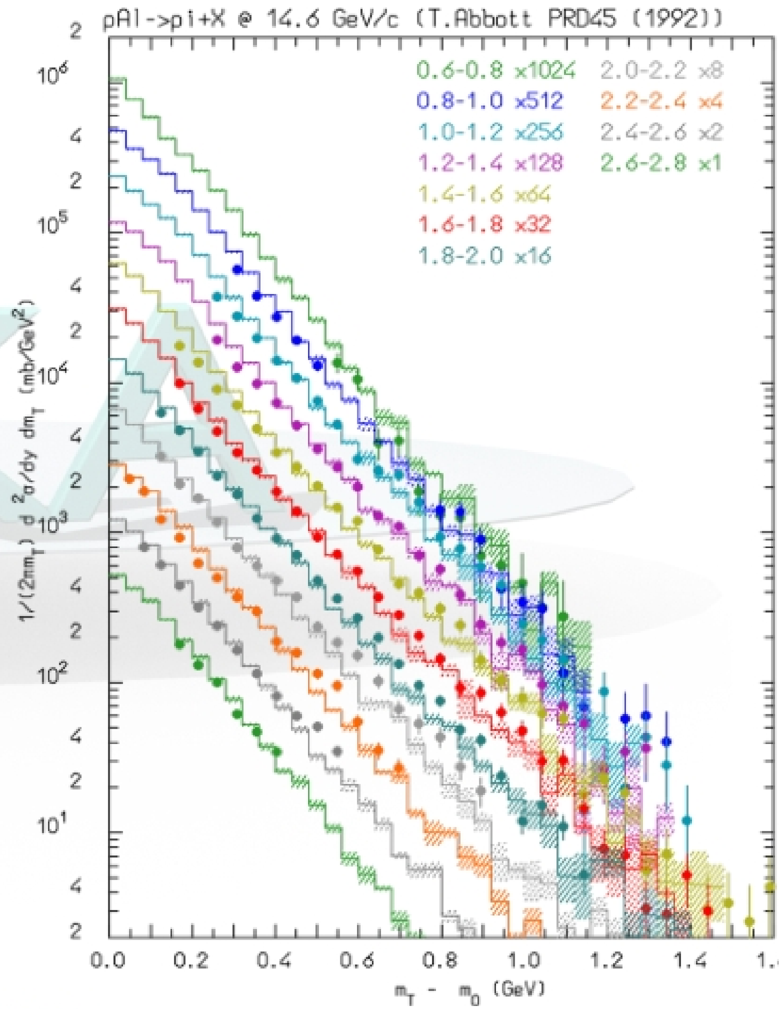
pBe, pAl @ 14.6 GeV/c



π^+, π^-, K^+, K^-, p, d, rapidity distributions for pBe @ 14.6 GeV/c (left)

π^+ production double differential cross section for pAl @ 14.6 GeV/c as a function of the transverse mass, for different rapidity intervals

Symbols: exp. data
Histos: FLUKA



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Formation zone: early evidence

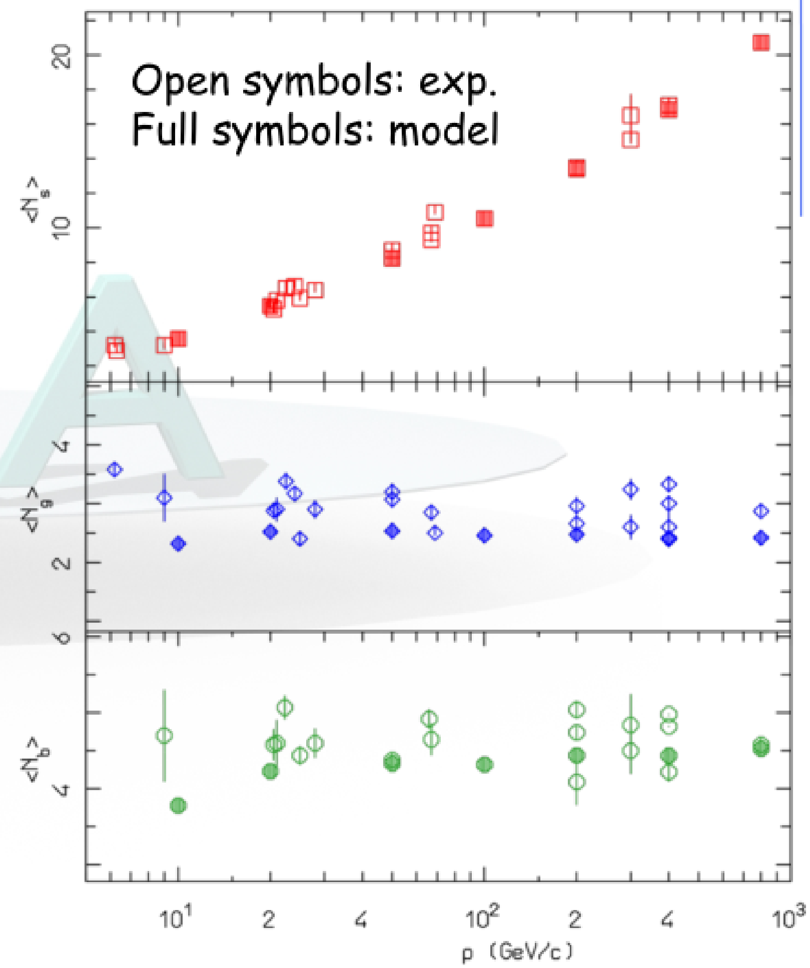
Many early experiments with high energy beams were using emulsions as target and recording media at the same time

Charged particle tracks were classified into:

- ***Shower or fast tracks***: weakly ionizing particles, around the ionization minimum (E> 2-3 times their mass), ***mostly pions*** → a measure of the particles produced in the ***primary collisions***
- ***Grey tracks***: mildly ionizing particles, typically ***intermediate energy protons***, → a measure of ***re-interaction*** products
- ***Black tracks***: heavily ionizing particles, typically ***evaporation products*** (p, α, ...), → a measure of the ***excitation energy*** left in the residual nucleus

Evidence: shower particles continue to grow as expected, cascade and evaporation ones, are fully saturated above 10 GeV → only the slowest fragment(s) of each primary interaction have a chance to re-interact and feed the intranuclear cascade and the excitation energy

Average multiplicities in proton-emulsion experiments



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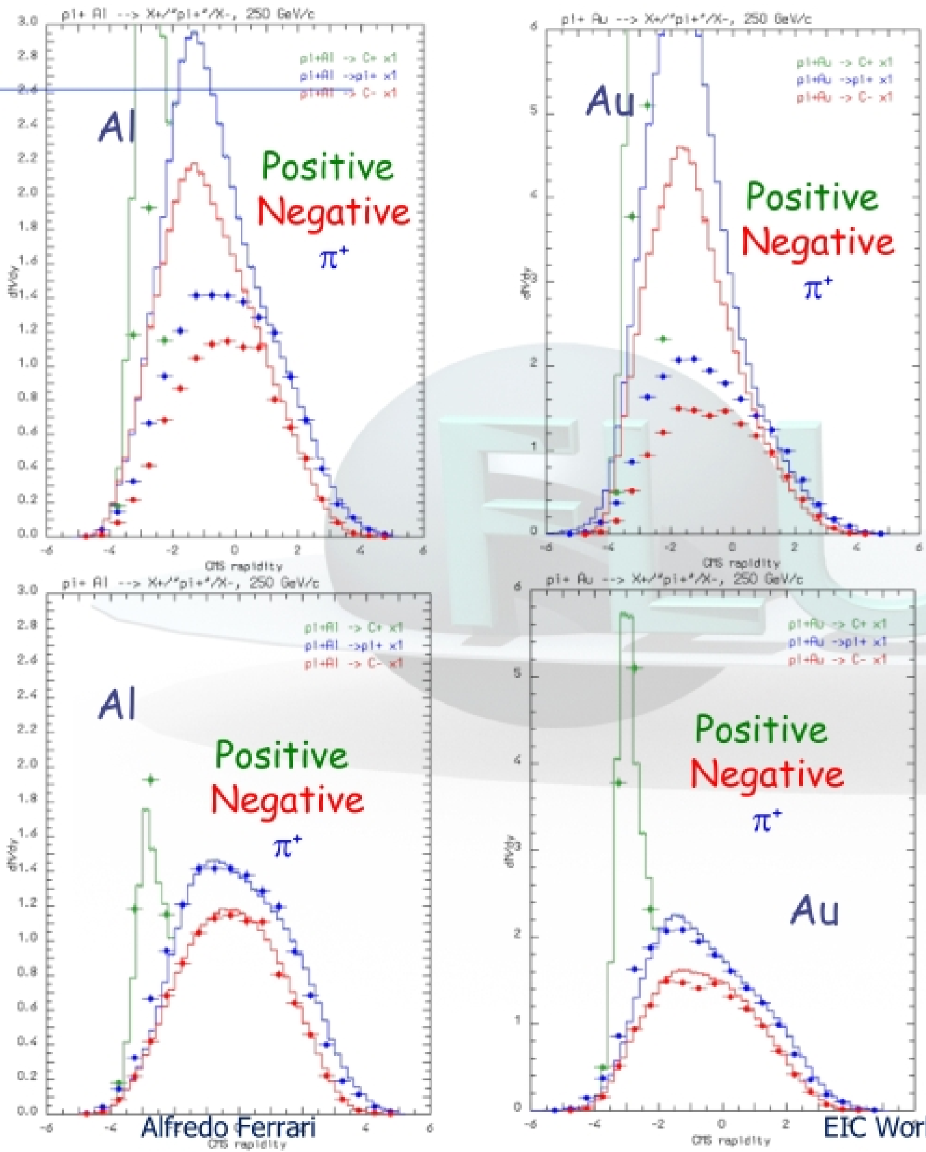


Formation zone: effect on hadron-induced reactions

Rapidity distribution of charged particles produced in 250 GeV π^+ collisions on Aluminum (left) and Gold (right)
Histos: FLUKA
Points: exp. data (ZPC50, 361).

Top: without formation zone

Bottom: with formation zone

Pions in FLUKA: nuclear medium effects

Free π N interactions ⇒
- ⇒ Non resonant channel
- ⇒ P-wave resonant Δ production

$\pi + N \to \Delta$ in nuclear medium	⇒ decay	⇒ elastic scattering, charge exchange	
	⇒ reinteraction	⇒ Multibody pion absorption	

Breit-Wigner form with width Γ_F

$$\sigma_{res}^{Free} = \frac{8\pi}{p_{cms}^2} \frac{M_\Delta^2 \Gamma_F^2(p_{cms})}{\left(s - M_\Delta^2\right)^2 + M_\Delta^2 \Gamma_F^2(p_{cms})}$$

An "in medium" resonant σ (σ^A_{res}) can be obtained adding to Γ_F the imaginary part of the (extra) width arising from nuclear medium

$$\tfrac{1}{2}\Gamma_T = \tfrac{1}{2}\Gamma_F - \mathrm{Im}\,\Sigma_\Delta \qquad \Sigma_\Delta = \Sigma_{qe} + \Sigma_2 + \Sigma_3$$

(Oset et al., NPA 468, 631)

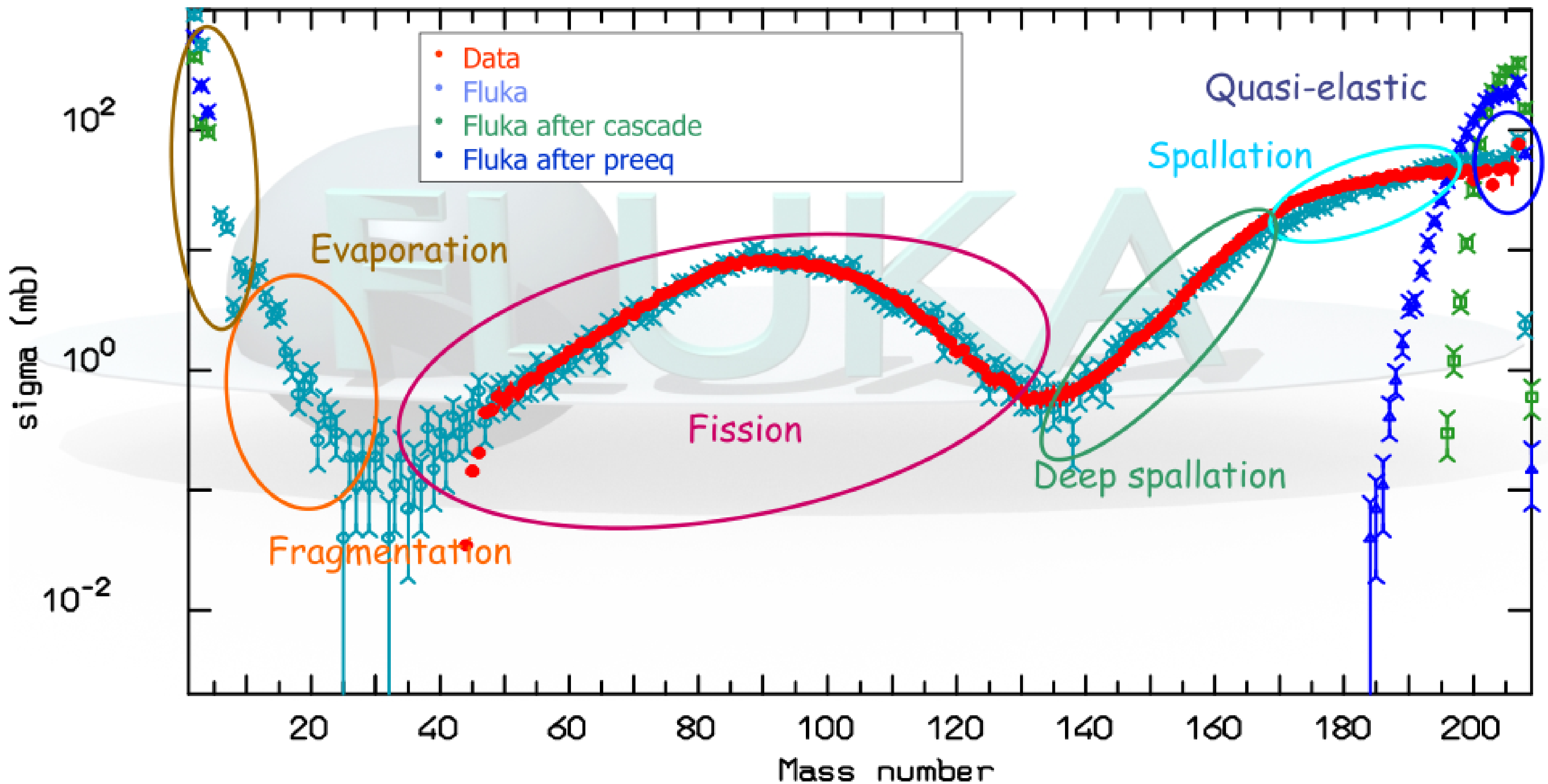
quasielastic scattering, **two** and **three** body absorption

The in-nucleus σ_t^A takes also into account a two-body s-wave absorption σ_s^A derived from the optical model

$$\sigma_t^A = \sigma_{res}^A + \sigma_t^{Free} - \sigma_{res}^{Free} + \sigma_s^A \qquad \sigma_s^A(\omega) = \frac{4\pi}{p}\left(1 + \frac{\omega}{2m}\right) \mathrm{Im}\, B_0(\omega)\, \rho$$

Example of fission/evaporation

1 A GeV ^{208}Pb + p reactions Nucl. Phys. A 686 (2001) 481-524

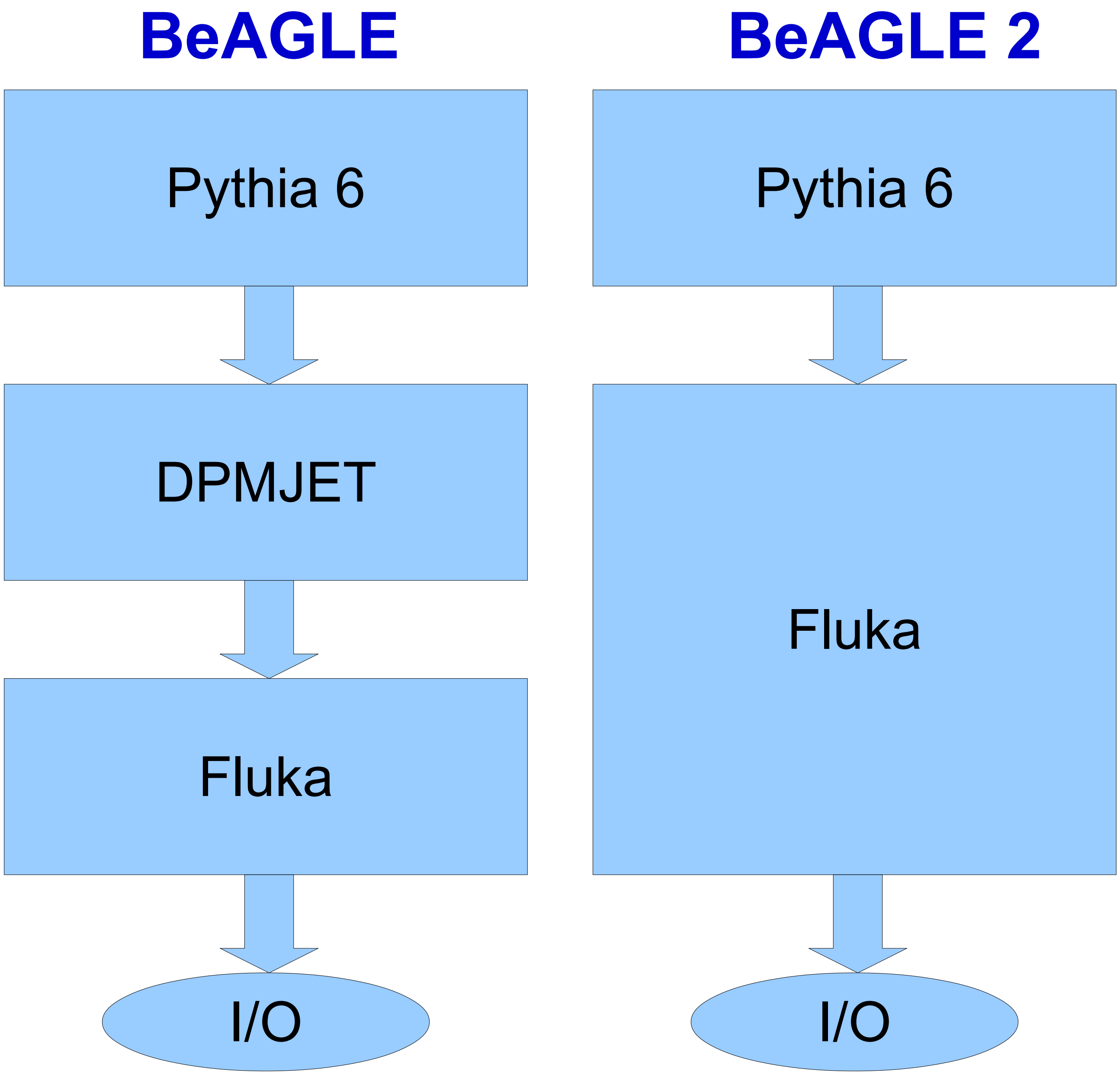


Questions:

- How can we help in general?
- Would a Peanut interface to a eN generator (similar to the built-in one for Nundis) be of help?
- What about formation time for DIS events?
- ...

Thanks for your attention

Much simpler BeAGLE?



<u>Advantages</u>

Fluka is actively developed/supported.

More reliable nuclear physics.

<u>Disadvantages</u>

Black box

Trickier to implement multinucleon effects in the hard interaction...

Questions

- GiBUU+SMM
  - I suggested that they look at the E665 SC data.
    - Will follow up with an email.
  - Do we agree that they match HERMES data in the current jet. If not, what is wrong?
- FLUKA (PEANUT)
  - Alfredo offered to provide an interface for e+N (i.e. Pythia) to access their e+A (including INC etc.).
    - Will follow up with an email. Thoughts?
  - Will ask some other questions (e.g. $M_{nucl}(A,Z)$).